Decoherence and the Quantum Zeno Effect *

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The quantum Zeno effect (QZE) is the inhibition of transition between quantum states as a result of frequent or continuous observations on the state [1]. Ghirardi et al [2] have shown through general arguments based on time-energy uncertainty relations that it is extremely difficult to observe this effect in the case of spontaneous decay. Recently Nakazato et al [3] have also analysed the QZE in the case of neutron spins and shown that the limit of 'continous measurements' is unphysical. QZE was observed experimentally by Etano et al [4] in an rf transition between two $^3Be^+$ ground state hyperfine levels 1 and 2 (Fig. 1).

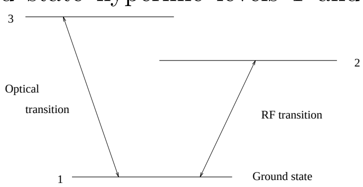

Fig. 1 *Energy-level diagram for the QZE experiment [4]*
Level 3 can decay only to level 1. The measurement is carried out by driving the $1 \rightarrow 3$ transition with a short optical pulse and observing the presence or absence of spontaneously emitted photons from level 3 corresponding to the atom being projected to the level 1 or 2. A 'freezing' of population in one level as a result of continuous measurements was observed. By using the postulate of projection or reduction of the wave function Etano et al have shown that in the limit of infinitely frequent measurements, the probablity of one of the levels being populated goes to unity [4]. Frerichs and Schenzle [5] have shown that the outcome of the experiment can be explained by looking at the optical bloch equations for the three-level system without appealing to the projection postulate or the 'wave function collapse'.

We propose that the measurement here can be explained by the 'environment induced decoherence' theory [6] which is based on the understanding that during the measurement process the system is not isolated but coupled to an external environment, which leads to a decoherence in the reduced density matrix of the system, driving it to a diagonal form. The crucial point here is that the collapse does not take place instantaneously but over a characteristic time scale, the 'decoherence time'. Let us consider the phenomenon of spontaneous emission (SE). SE decay rates emerge naturally when a completely quantized field treatment including the coupling to the field vacuum modes is considered in the Weisskopf-Wigner theory [7]. In the QZE experiment of Etano et al [4] the two-level system (levels 1 and 2) constitutes the 'system', the level 3 is the 'apparatus' and the collection of vacuum modes coupling to level 3 is the 'environment' (Fig. 2).

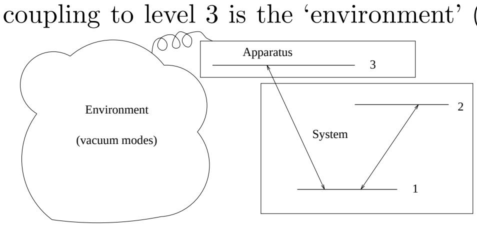

Fig. 1 *Schematic diagram of the model [8]*

The system-apparatus interaction is through the short pulses that connect level 1 and 3. The equation for the reduced 'system-apparatus' composite after tracing over the environment variables are the optical Bloch equations considered by Frerichs and Schenzle [5] which successfully explain the QZE. It is obvious that the decoherence time for each measurement is the SE lifetime. It is interesting to note that it sets a fundamental limit on the requirement of 'continous measurements' for QZE since the measurements cannot be spaced closer than the SE lifetime of the third level. Interestingly this is the time-energy uncertainty relation that Ghirardi et al [2] argued about.

To summarize, we have shown [8] how the time-energy uncertainty relation emerges naturally as a fundamental limit on achieving 'continuous measurements' as required in the QZE when we analyse the QZE problem using the environment induced decoherence approach. This is in agreement with the studies of Ghirardi et al [2] and the predictions of Nakazato et al [3].

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